# A Very Low Power, Highly Integrated Multichannel Scaler


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*Abstract* - **Multichannel Scaler (MCS) electronics are often used in lidar-based photon counting applications. The NASA SBIR Phase-I effort resulted in a highly integrated, low power, USB-based MCS hardware prototype and Windows-based software. The Phase-II project focused on expanding the Phase-I MCS development in creating a complete flexible lidar data acquisition "system-on-a-card." Key motivations in the design of the card were low power, compact form factor, and flexibility for use across multiple projects including embedded and PC-based systems. Many lidar-based photon counting systems use similar components and are made up of numerous circuit cards. The Phase-II effort consolidated many of the functions common to these projects into a single piece of electronics thereby increasing system reliability and reducing system power, mass, and complexity. Both the Phase-I and Phase-II deliverables have been well received by the NASA and science communities worldwide. The Phase-III effort funded by ESTO focuses on the migration of the Cloud Physics Lidar (CPL) data system to an unmanned aerial vehicle (UAV) platform such as the Global Hawk. Capabilities such as real-time uplink commanding and quick-look data downlink and analysis will demonstrate new in-flight functionality to enhance data collection. The current efforts provide another stepping stone in the development of a compact space-based photon counting lidar data system.**


## I. Introduction

Size, power, and performance are the typical trade-offs in developing electronics instrumentation. Such considerations are critical in remotely deployed, embedded systems or in portable, compact systems. In order to address these concerns for NASA's airborne and ground-based photon-counting lidar programs, we have developed a series of multichannel scaler (MCS) cards and systems. Such hardware has been designed for reliable, continuous operation in harsh environments such as those experiencing extended temperature ranges and high-altitude (low-pressure) environments.

Many MCS systems on the market are physically large or consume much power, and it is not uncommon to find large plug-in cards or rack-mounted boxes in excess of 20 Watts [1]. While suitable for many environments, electronics requiring such mass and power are unacceptable for use in the compact, low-power data systems being developed by NASA.

Multichannel scaler cards are used for pulse counting, binning, and accumulation. By integrating over many laser output pulses, the signal-to-noise ratio is increased and a wide dynamic range is achieved. A MCS is a key component of a photon counting lidar data system.

In this paper, the term "highly integrated," when applied to the MCS development, implies the following:

- Single chip solution for most of the digital circuitry;
- Multiple detector inputs on a single circuit card;
- Integrated on-chip memory;
- Use of low-power devices;
- Mainstream and open-systems interfaces.

All of our MCS cards and systems employ the use of SRAM-based, reprogrammable field programmable gate array (FPGA) technology that allows for project-specific customizations and easy system-level replacement for older, larger, and power-hungry electronics. FPGA-based customization allows for hardware re-use and decreases risk associated with cost, development, and end-product testing of new hardware. Such customization also facilitates deployment of the MCS hardware into existing lidar systems (as part of an upgrade), since external system-level signals can be emulated by the hardware.

The baseline performance parameters were developed to satisfy NASA GSFC's Cloud Physics Lidar (CPL) and Automated Geophysical Observatory (AGO) instrument requirements. The CPL instrument is a high repetition rate (i.e. 5 kHz), three-wavelength (1064nm, 532nm, and 355nm), low laser output pulse energy (i.e. 50μJ @ 1064nm, 25 μJ @ 532nm, and 50 μJ @ 355nm) airborne photon counting based system. The CPL instrument is designed to provide cloud profiling (including internal cloud structure and phase, and particle size), aerosol and plume profiling, and optical depth. The CPL data system has 30m vertical resolution and integrates pulses every 0.1 seconds (i.e. every 500 laser pulses) [2]. Trade-offs in performance versus power were made based on the CPL instrument with consideration given to other similar multi-kilohertz, photon counting atmospheric lidar programs at GSFC as well. We carefully traded-off MCS performance in that we designed our MCS cards to exceed all CPL requirements, but we did not attempt to add additional resolution which would go unused by the user community at the expense of size, power and level of integration.

Our Phase-I SBIR efforts focused strictly on card-level hardware integration while the Phase-II and Phase-III SBIR efforts focused on card and system-level integration geared to newer instrument platforms such as unmanned aerial vehicles (UAVs) and space-based systems.

To date, our MCS cards and systems have supported more than seven NASA lidar programs and more than twelve government (non-NASA), university and industry-wide lidar programs with approximately 70 units delivered to the science community. NASA GSFC has funded most of our development via the SBIR program.

## II. HISTORY & PAST WORK

### *A. Development History*

In 2000, the CPL instrument and AGO lidar programs were in need of a PC/104-based MCS solution suitable for airborne operation and remotely deployed applications, respectively. In order to address the needs specific to the CPL instrument in preparation for the SAFARI 2000 field campaign in August and September 2000, ASRC Aerospace developed a PC/104-based multichannel scaler card called the AMCS-5 [2]. This card accommodates five detector inputs in a compact industry-standard form-factor. It provides up to 4K 16-bit wide bins for each detector channel. Key MCS parameters such as bin size, number of bins, and integration cycle length are all supported in the hardware and are user programmable. The AMCS-5 card was readily integrated with the other PC/104 cards in the CPL data system's stack that included a CPU card, video card, serial communications card, two A/D cards, and a card containing extra circuitry for a total of seven circuit cards. The AMCS-5 card also provides discrete outputs on each laser shot that may be used to reset energy monitors and control the A/D converters.

The AMCS-5 card features a double-buffered ping-pong memory associated with each detector channel such that data acquisition continues while acquired data is transferred back to the host computer. The AMCS-5 card also has no dead time between bins. Therefore, continuous data acquisition, with no gaps, is possible.

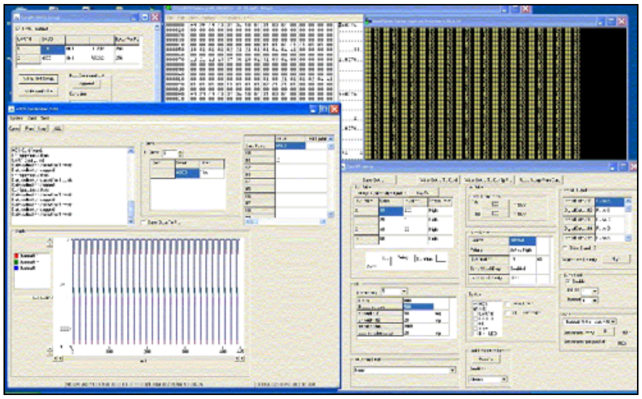
During the Phase-I SBIR efforts, ASRC Aerospace improved upon the AMCS-5 card features by adding a layer of hardware integration. This included embedding all FIFO memories into an on-card FPGA and providing a popular USB 1.1 host interface. The Phase-I deliverables consisted of the AMCS-USB circuit card which accommodates four detector inputs in a 4" x 4" form factor as well as software to control the hardware and collect and log data. The AMCS-USB card provides up to 4K 16-bit wide bins for each detector channel. Like the AMCS-5 card, it also has a double-buffered ping-pong memory buffer and provides several output pulses for system-level functions. The AMCS-USB card was made with expansion potential such that by replacing several components, the same circuit card can accommodate eight detector inputs. In this expanded mode, the card is called the AMCS-USB+ card.

During the Phase-II SBIR efforts, ASRC first developed several different FPGA loads that demonstrated the benefits of the reprogrammable FPGA technology and the advantages associated with the new level of integration of the AMCS-USB and AMCS-USB+ cards [3]. For example, using the same physical hardware, we demonstrated various configurations such as:

- Eight detector inputs with 4K 16-bit wide bins for each detector channel (which is our standard AMCS-USB+ configuration);
- Four detector inputs with 8K (instead of 4K) 16-bit wide bins for each detector channel;
- Four detector inputs with 4K 24-bit wide bins (instead of 16-bit wide bins) for each detector channel.
- A faster pulse counting approach with greater than two times the resolution at the expense of fewer detector channels.

The Phase-II effort then focused on an even higher level of card and system level integration with the development of the Advanced Photon Counting System (APCS) circuit card and software. A survey of NASA photon counting lidar systems was used to determine a superset of requirements for the APCS card. Many photon counting lidar systems require components such as a multichannel scaler for pulse collection, A/D converter for housekeeping, serial communication ports for auxiliary data, hard drive storage, time tagging, and quicklook data capability. The resulting Phase-II deliverable was a single circuit card that provides the key functionality of all of the seven cards of the original CPL data system. The APCS card, then, may be considered as a "system on a card." A Windows based GUI allows the user full customization of all APCS settings as well as for logging and plotting data as shown in Figure 1.

FIGURE 1
APCS Software Screenshot



The APCS card accommodates ten detector input channels and provides a high-speed USB 2.0 interface. It provides a double-buffered ping-pong memory with an effective 4K 16-bit wide bins for each detector channel. In addition to the MCS function, the APCS card also has the following features:

- Software controlled MCS parameters;
- Non-volatile memory to store settings and start-up command table for a "live at startup" capability;
- Serial ports for collection of serial data (i.e. GPS or other navigational data), quicklook data retrieval, and commanding;
- 16 analog inputs for housekeeping data collection;
- 10 programmable output pulses for system-level functions;
- Attended (via the USB 2.0 interface) and remote modes of operation suitable for lab-based or remotely deployed and airborne platforms;
- 2.5" IDE laptop hard drive direct connection for remotely deployed data storage and retrieval. Both solid state or mechanical drives are supported;
- Expansion connector for 1 GHz high-resolution front-end daughtercard;
- Ability to be cascaded with multiple cards;
- Single +5V input.

Prior to the Phase-II APCS design, ASRC Aerospace's MCS card development was somewhat segmented in that the AMCS-5 card was suited for embedded, remotely deployed applications, while the AMCS-USB card was suited for attended laptop-based systems. The APCS card blurs the remote versus attended aspect in that it is suited for both types of applications.

The APCS card was also designed with a daughtercard interface. Later this year, ASRC Aerospace, in conjunction with a third party, intends to provide a 5-detector input, 1GHz front-end that can be used with the existing APCS card. This will provide the opportunity to support not only atmospheric lidar programs but potentially other applications as well such as imaging, nuclear, and medical programs.

Table 1 shows a comparison of the various developed MCS cards. Table 2 shows a comparison of ideal data transfer rates. The various MCS cards are shown in Figure 2.

TABLE 1
MCS Feature Comparison Table

| | **AMCS 5** | **AMCS USB** | **AMCS USB+** | **APCS** |
|---|---|---|---|---|
| # Channels | 5 | 4 | 8 | 10 |
| Interface | PC/104 | USB 1.1 | USB 1.1 | USB 2.0 |
| Dimensions | 3.6" x 3.8" | 4" x 4" | 4" x 4" | 10.5" x 6" |
| Max Count Rate* | 112 MHz | 100 MHz | 100 MHz | 115 MHz |
| Power / Power Per Channel | 2.2W / 0.44W | 3.2W / 0.80W | 6.2W / 0.77W | 4.5W / 0.45W |
| Double-Buffered Memory | Yes | Yes | Yes | Yes |
| Auxiliary Functions | No | No | No | Yes |

* *Max count rates achieved with detector input constraints*

TABLE 2
Throughput Comparisons (Ideal)

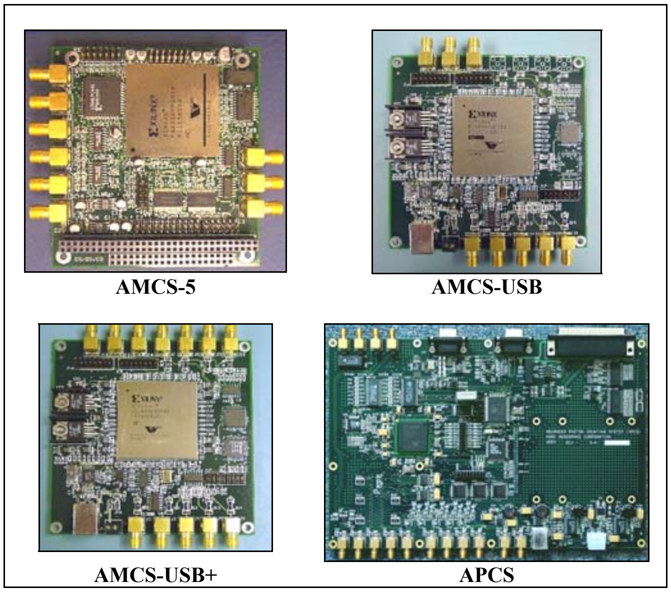
| **Interface** | **Ideal Data Transfer Rate** |
|---|---|
| PC/104 (ISA) – 16-bit parallel | 40 Mbps (estimated) |
| USB 1.1 (full-speed) | 12 Mbps |
| USB 2.0 (high-speed) | 480 Mbps |

### *B. Spin-Ins and Spin-Offs*

The MCS development efforts have been recognized by NASA's Office of Technology Transfer due to both their acceptance and usage by the NASA and non-NASA communities. ASRC's efforts have been featured in NASA Spinoff 2004 for the considerable NASA use of the products developed under the SBIR program [4]. In addition, these MCS cards have been featured in NASA Tech Briefs [5]. Finally, the SBIR has been featured as a success story on the NASA SBIR web page [6].

NASA GSFC has already demonstrated the effectiveness of the "spin-in" concept in that numerous multi-kilohertz photon counting based lidar programs at NASA now utilize ASRC Aerospace's AMCS-5, AMCS-USB, and APCS hardware.

FIGURE 2
ASRC Aerospace's MCS Cards




These GSFC lidar programs include:

- Cloud Physics Lidar (CPL)
- Thickness from Off-beam Returns (THOR)
- Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)
- Micropulse Lidar (MPL) Type-4 Data System
- CO2 Detection Lidar Testbed
- Multi-Channel Doppler Wind Detection System
- Goddard Lidar Observatory for Winds (GLOW)

The MCS cards are operated in laboratories, trailer-based systems, and airborne (ER-2 and WB-57) systems. The cards have been used in various data collection and satellite validation campaigns such as SAFARI 2000, CRYSTAL-FACE, IHOP 2002, THORPEX, GLAS Cal/Val, and AVE. Such campaigns have been geared to improving weather forecasting and satellite (i.e. GLAS, MODIS, AIRS, AURA) validation. Sample CPL data from the Aura Validation Experiment collected in November 2004 are shown in Figure 3.

Of note, the Micro Pulse Lidar Type-4 systems utilize a data system based on the AMCS-USB cards. Over 15 MPL Type-4 systems have been delivered and deployed worldwide.

As a "spin-off," the MCS cards have also been successful, as ASRC Aerospace has a diverse non-NASA customer base that includes:

- Pacific Northwest National Laboratory (PNNL) / Battelle
- Sigma Space Corporation
- Science and Engineering Services Incorporated (SESI)
- Arizona State University
- Observatoire Cantonal de Neuchatel (ON)
- Montana State University
- BNFL Instruments, Inc.
- Mauna Loa Observatory / NOAA CMDL
- Sigma Space
- Kyoto University
- Tokyo Metropolitan University
- Environment Canada

## III. CURRENT EFFORTS & GOALS

The Phase-III SBIR is currently underway. The goals of this effort include the migration of the CPL data system from the ER-2 and WB-57 high-altitude aircraft environment to a UAV platform. In addition, during this phase, a trailer based lidar system, such as the GLOW system, may be migrated to a similar platform.

In 2004, ASRC upgraded the CPL data system and replaced the AMCS-5 card and PC/104 stack with the APCS card. The new system was flown on the WB-57 during the Aura Validation Experiment (AVE) in October-November 2004. This system is shown in Figure 4.

In order to make the current CPL system UAV-ready, several features must be added to the CPL instrument.

FIGURE 3
CPL Data Obtained With APCS-Based Data System

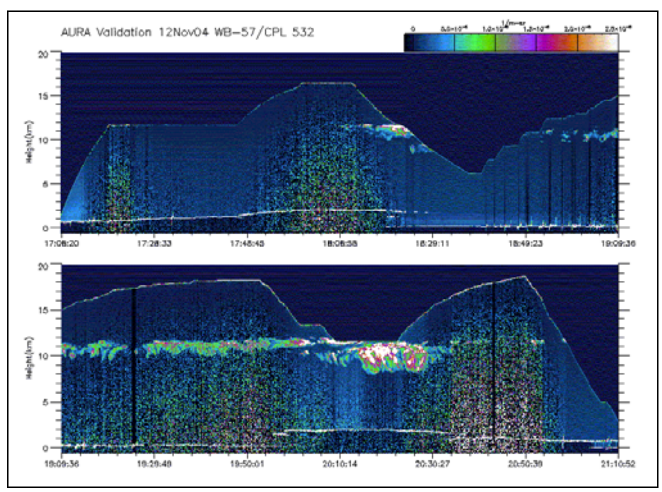


FIGURE 4
CPL Data System with APCS Card

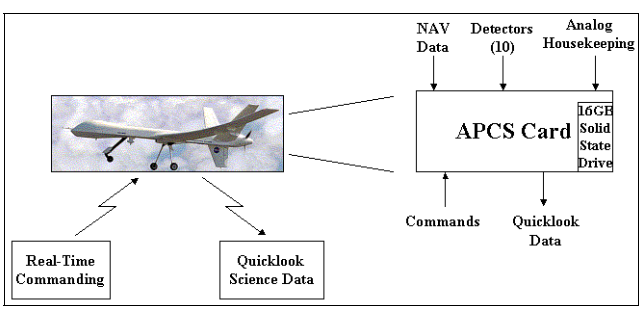
These UAV-specific features include:

- Real-time commanding for in-flight parameter updates;
- Quicklook data support for in-flight data quality evaluation;
- Additional hardware adapters for compatibility between the UAV interface and the APCS interfaces;
- A master power controller that enables or disables all AC and DC power in the system.

While the master power controller will result in a new hardware deliverable, "hooks" for the quicklook data evaluation and real-time commanding are already supported by the APCS card hardware. On-card firmware and ground system computer software development will occur in order to make use of these hardware hooks. A diagram showing how the APCS hardware fits into the UAV-based system is shown in Figure 5.

The technology readiness level (TRL) for this effort is currently at a TRL 4, which corresponds to "Component and/or breadboard validation in laboratory environment." At the completion of this effort, we plan progress to a TRL 6, which corresponds to "System/subsystem model or prototype demonstration in a relevant environment."

FIGURE 5
APCS Card in UAV-Based Platform




## IV. FUTURE DEVELOPMENTS & CONCLUSION

In 2000, ASRC Aerospace developed the AMCS-5 card, which was a five-detector input PC/104-based multichannel scaler card. This card did not have on-chip memory, and parts filled both sides of the circuit card measuring at 3.6” x 3.8”. In Phase-I, the AMCS-USB card was developed with an enhanced the level of integration and a USB 1.1 interface, thereby making it suitable for a large number of on-going and future NASA programs.

The APCS card, developed in Phase-II, demonstrated a marked improvement upon the AMCS-USB card and offered new functions not typically attributed to an MCS card. That is, the ten-detector channel MCS function is merely one of many functions provided by the APCS card. All of these cards have been used in lidar photon counting based data collection programs at NASA GSFC and industry-wide.

By utilizing FPGA technology as well as a language-based design methodology (VHDL) for the FPGA logic, a significant portion of the MCS design may be readily migrated to a radiation-tolerant device suitable for the space environment. For example, while the Xilinx Virtex, Virtex-EM, and Virtex-II devices are used in the current implementations, a space-based lidar would require the use of an Actel RTAX-S or RTSX-S FPGA device or a Xilinx XQVR FPGA device. These latter devices have space heritage and would be suitable target devices. The high-altitude airborne campaigns to-date lend credibility for the MCS designs in a “space-like” environment. Since the ER-2 aircraft flies at above 94% of the Earth’s atmosphere at approximately 65,000 feet (20 km), its instruments act as spaceborne simulators [2]. ASRC Aerospace will seek opportunities to migrate the current designs for space flight photon counting lidar programs.

The MCS development efforts funded by NASA have benefited numerous NASA and university / industry sponsored photon counting based lidar programs. These MCS cards, exhibiting low power, small size, and rich feature sets, have been well accepted by the scientific community.

## ACKNOWLEDGMENT

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## References


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